COsmology and Molecule Explorer

Di Li

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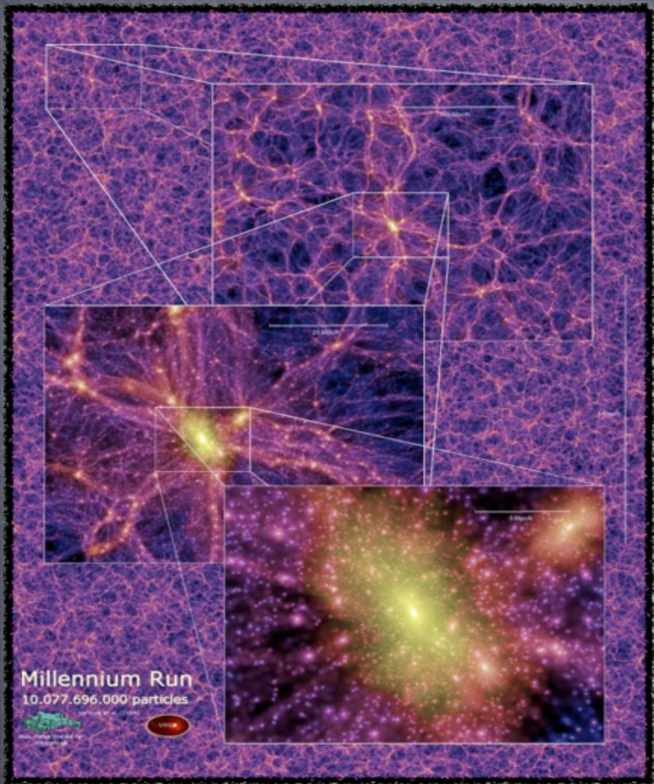
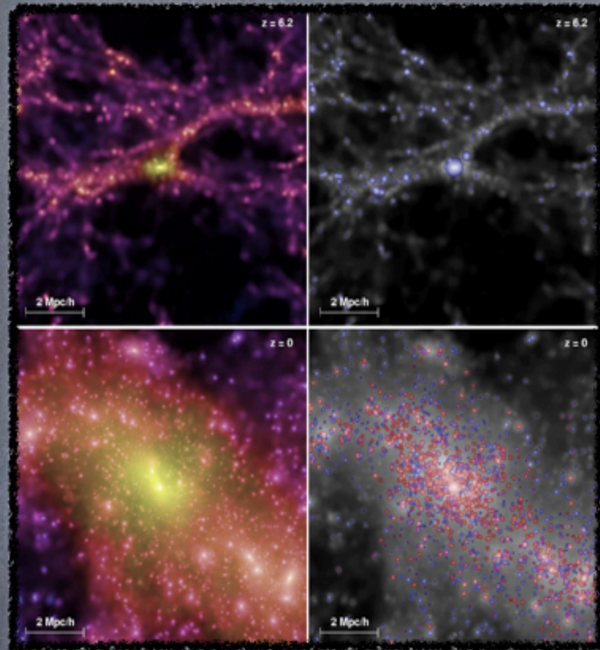
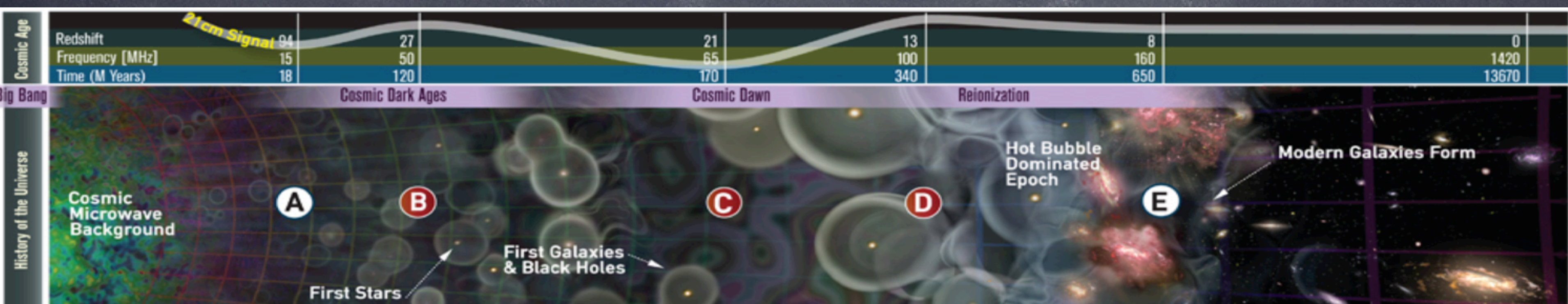
Lighting up The Dark Universe

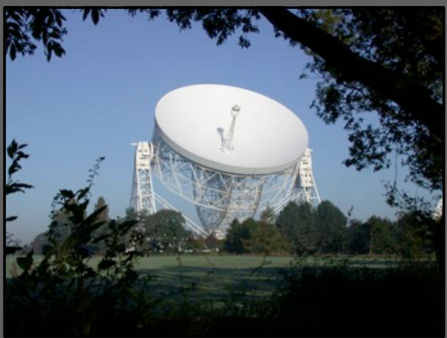


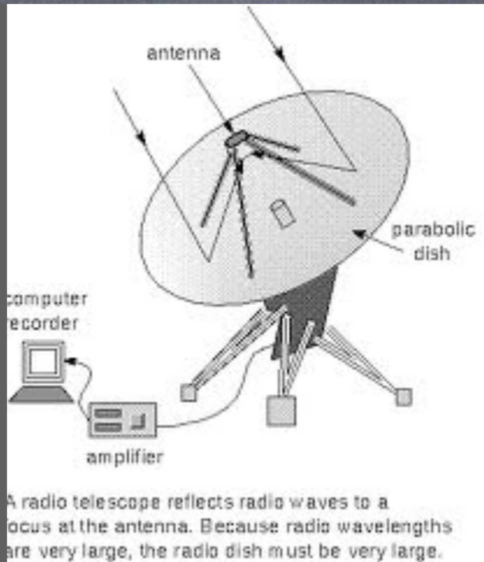


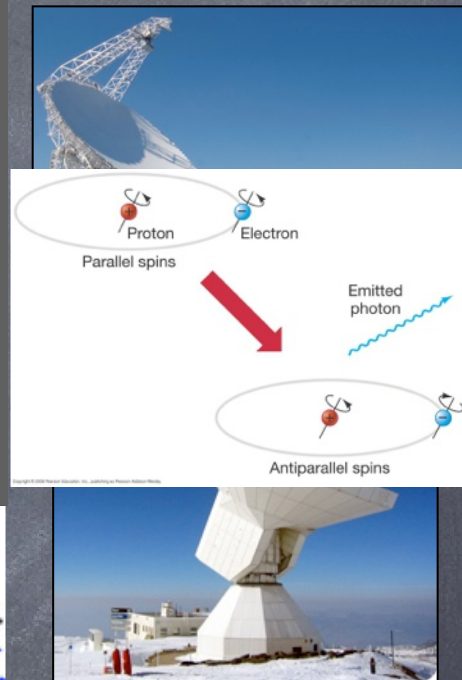
(Springel et al. 2005, Nature)

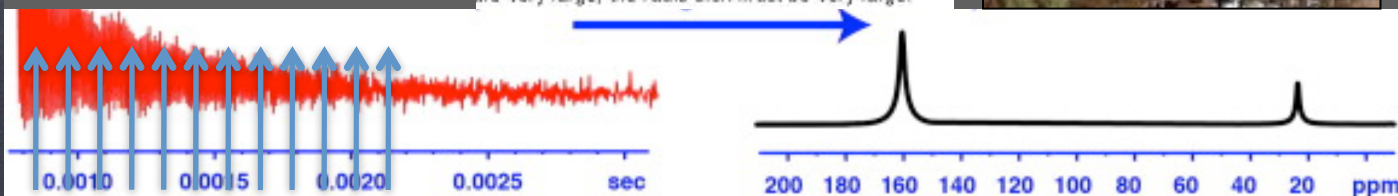


Lines of Radio









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射电天文对认识宇宙的<u>历史性贡献</u>

发现了： 星际氢原子、星际分子、星际气体、空间脉泽、宇宙微波背景辐射、脉冲星.

Discovery of Interstellar Gas

射电天文学前沿973
FAST
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Harold Irwin Ewen
and Ed. Purcell 1951

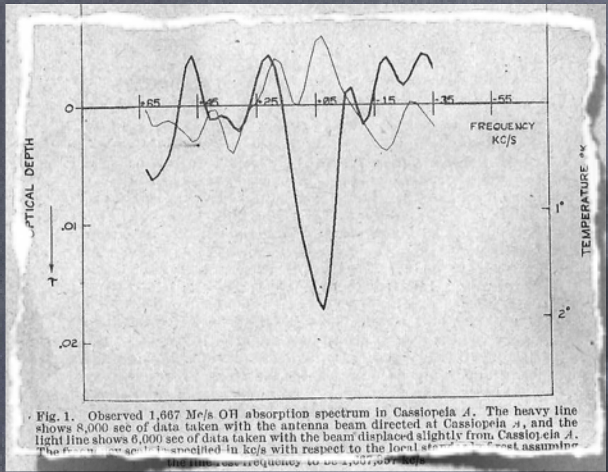
Harvard Univ.,

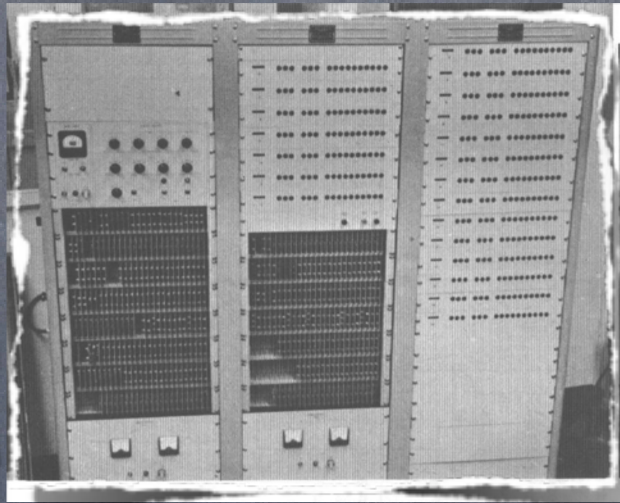
Feedhorn Telescope

开创了星际介质、银河系动力学结构、恒星形成及星际化学等许多天文领域

Molecular Universe

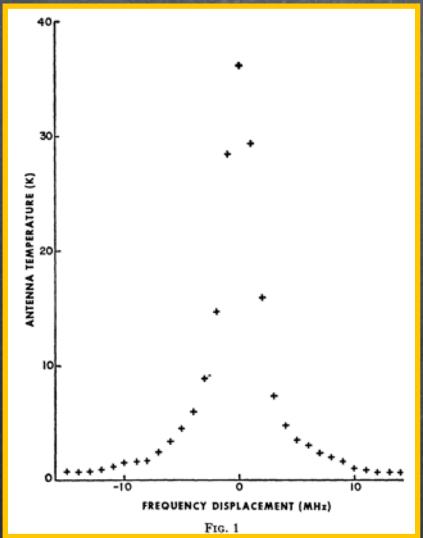
OH

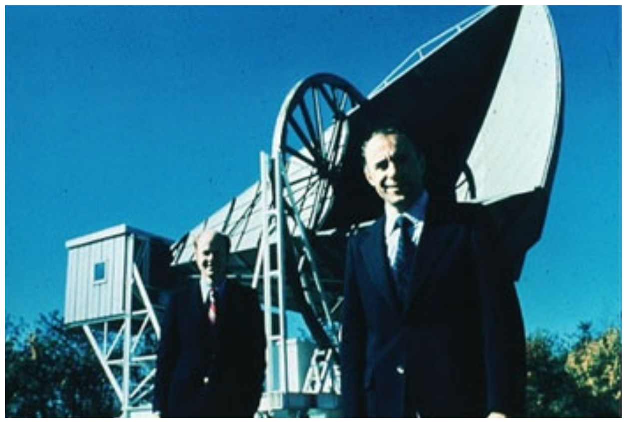




Weinreb et al. 1963 Nature

CO





Penzias, Jefferts, Wilson 1970, ApJL

COME: Report Outline

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1. Scientific Driver: Radio probe of cosmic evolution and chemistry

2. Current State: Unique advantage of space radio astronomy

3. Program: COME utilizes the extremely radio quiet lunar orbit to study HI evolution and examine content of diffuse ISM

1.: Evolution and Components of Gaesous Universe

Utilizes lunar orbit, shielding the Sun and the Earth, ultra wideband, stable systems, achieve an unprecedented high dynamical range, credible global spectrum of the universe.

From Dark to Light

Discover the absorption trough around Z~20, characterize the cosmic dawn

Gas Components

a) Carbon structures in space
b) identifying Large molecules
c) Remove the diffuse foreground for cosmology studies

2. Current State
Ground Projects

射电天文学前沿973 FAST
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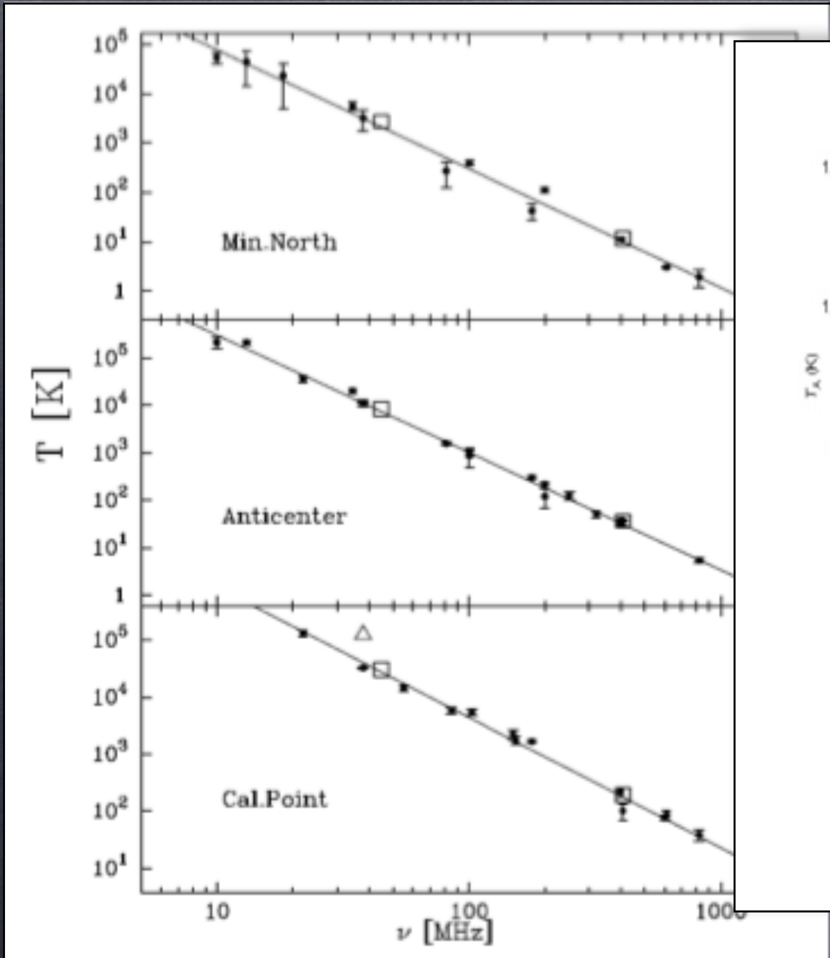
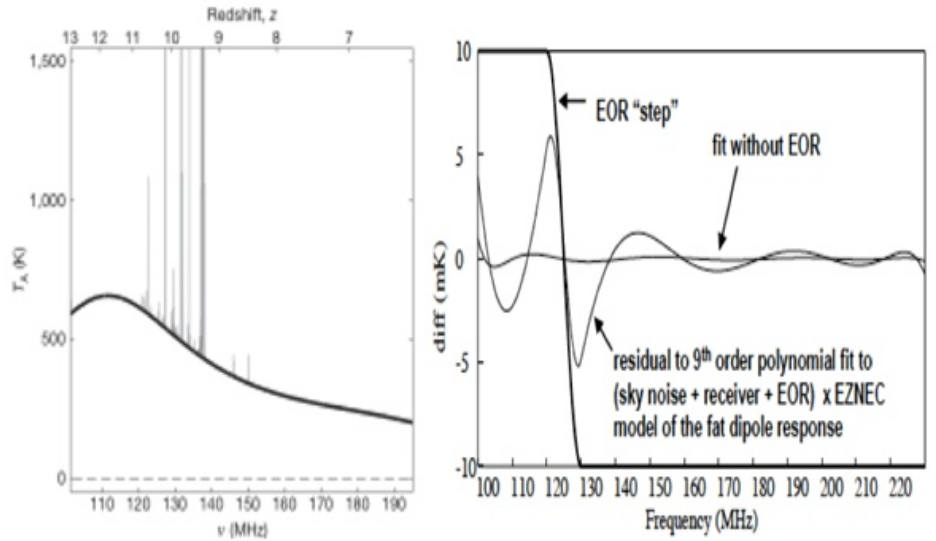
Ground-based Low Frequency Projects

Power spectrum and global spectrum wave bands at 10 cm and longer.

项目	波段	天线	科学目标	支持国家
EDGES	100-200 MHz	1x 四点天线	EoR	USA
MWA	100-200 MHz	16x双锥天线	EoR	Australia
21CMA	50-200 MHz	>20000 偶极天线	EoR	China
TianLai	~750 MHz	TBD	BAO	China
CHIME	400-800MHZ	5x20mx50m 柱状天线	BAO	Canada

"Choosing" Frequencies





图二：左：EDGES 实验所获的南天顶方向频谱。（Bowman & Rodgers 2010, **Nature**）**右：**模拟频谱和噪声残差的关系。（EDGES 技术报告，2005）

EDGES技术报告

MilkyWay Brightness Temperature
Guzman et al. 2011

HI Global Spectrum

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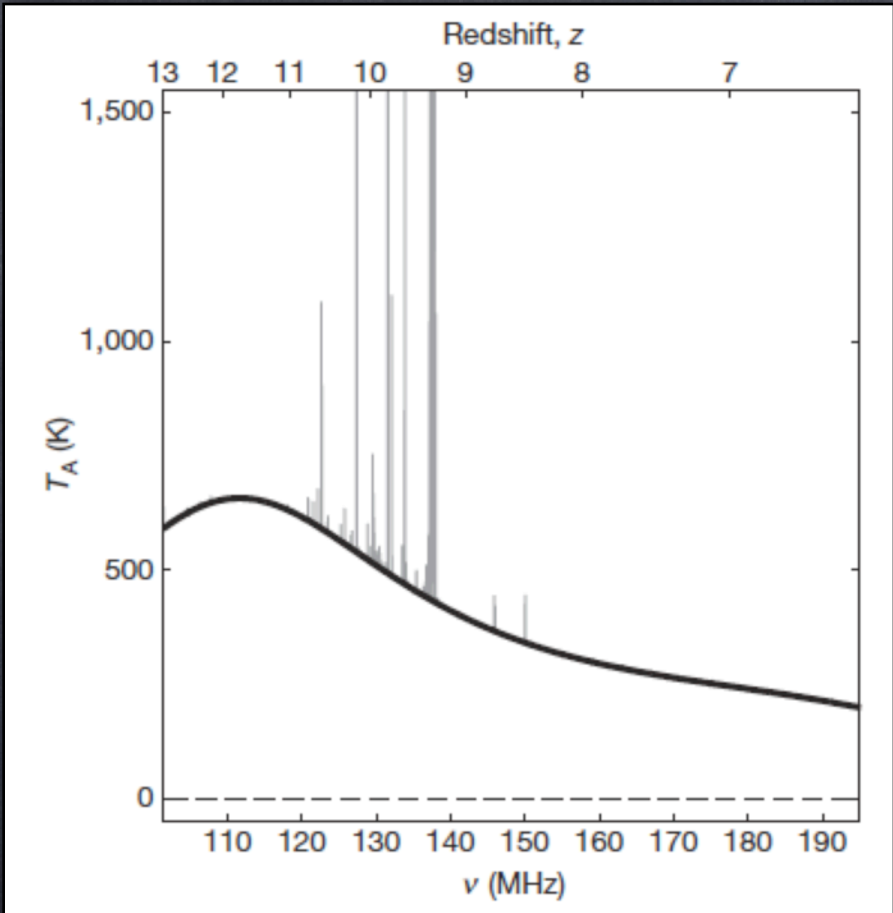


Bowman & Rogers 2010, **Nature**, 468, 796

COSMOLOGY

Hydrogen was not ionized abruptly

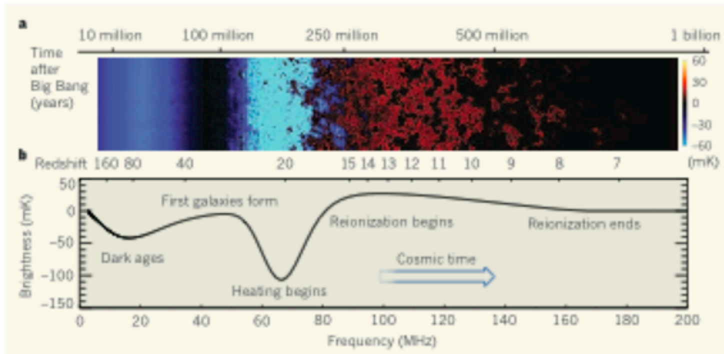
When and how the first stars and galaxies ionized the primordial hydrogen atoms that filled the early Universe is not known. Observations with a single radio antenna are opening a new window on the process. SEE LETTER P.796

JONATHAN PRITCHARD & ABRAHAM LOEB

Four hundred thousand years after the Big Bang, the Universe had cooled sufficiently for hydrogen atoms to form. Hundreds of millions of years later, the first stars and galaxies had produced ionizing ultraviolet radiation that broke the hydrogen atoms into their constituent electrons and protons. This process, termed reionization, marks a major cosmological phase transition. When and how rapid this transition was are important open questions[1]. On page 796 of this issue, Bowman and Rogers[2] implement a new technique that allows them to rule out models in which reionization occurs abruptly.

Their approach uses a simple radio antenna operating at low frequencies to measure the absolute radio intensity of the sky. Cosmic hydrogen atoms can emit or absorb light with a wavelength of 21 centimetres, a signal that is stretched (redshifted) on its way to Earth through the expansion of the Universe[3]. The redshifted 21-cm hydrogen signal, which falls within the radio regime, is expected to cut off at short, observed wavelengths that correspond to later times when the Universe was ionized. The authors' experiment to detect the global reionization step (EDGES) searches for the associated spectral step in the sky's intensity[4].

Our knowledge of the epoch of reionization is surprisingly limited. The lack of ultraviolet (UV) absorption by diffuse neutral hydrogen along the line of sight to the most distant quasars[5] (accreting black holes) indicates that the Universe is largely ionized at a redshift of less than about 6 — a billion years after the Big Bang. Yet observations of the cosmic microwave background[6] — radiation left over from the Big Bang — indicate that the Universe was filled with neutral hydrogen at much earlier times. Clearly, a transition must have occurred from a neutral to an ionized Universe, but even recent observations of high-redshift galaxies with the Hubble Space Telescope tell us little



Pritchard & Loeb 2010, **Nature**, 468, 772

Why Do Radio Spectroscopy From Space

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- Space Spectroscopy Advantage

  Example: Herschel HIFI May 2009; L2 Orbit

  Continuous coverage of Submm bands with high spectral resolution heterodyne receivers

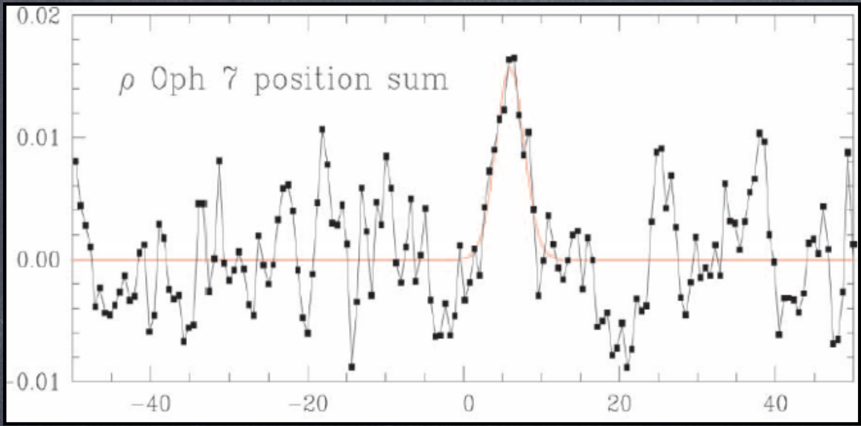
- Lunar Orbit Advantage

  1) Minimum radio interference in the inner solar

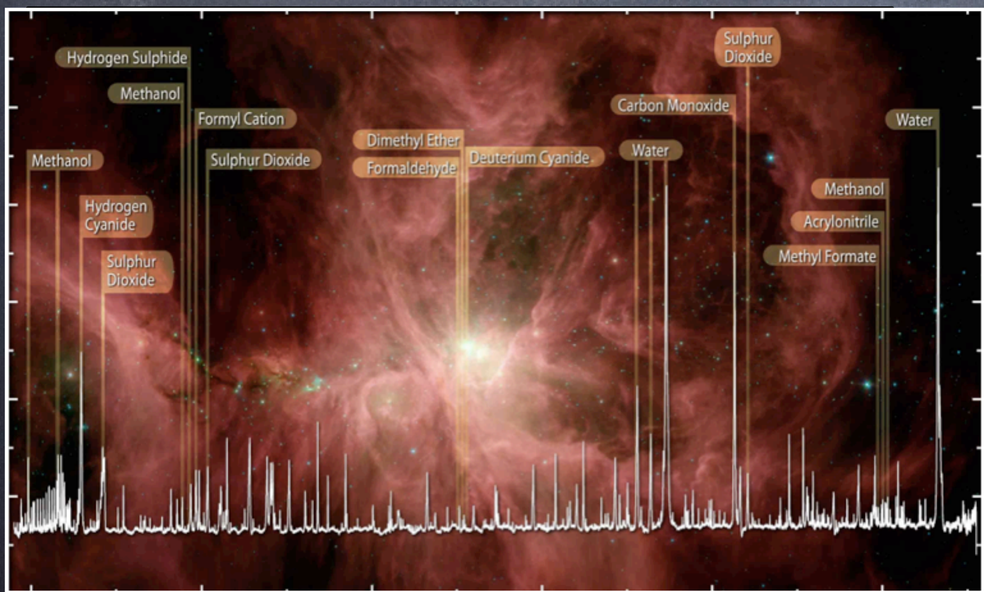
  => Integrated S/N and Stability>> $1/10^5$

  2) no atmospheric instability

Discover O2 in Space



Goldsmith, Li, Bergin et al. 2002, ApJ）



丰富的星际气体光谱

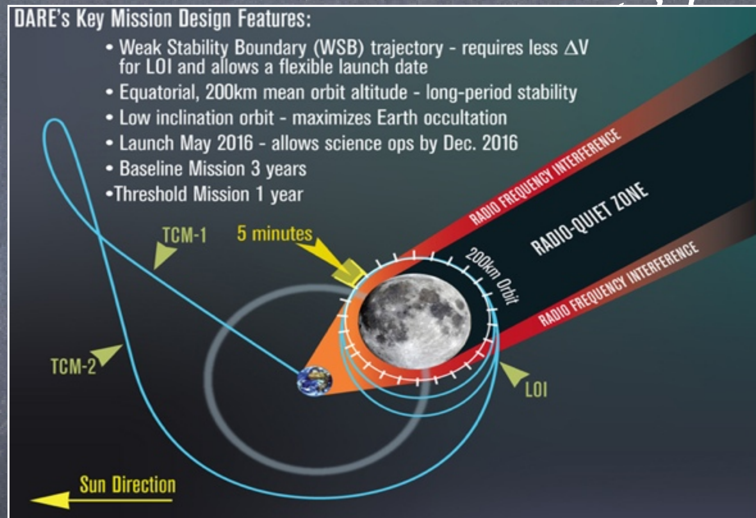
Herschel Line Survey HEXOS
Discover new molecules
e.g. Lis et al. 2010,
"Herchel/HIFI Discovery of
Interstellar Chloronium (H_2Cl+)",
A&A

and many more

2. Current State: Space

Lunar Based

- DALI (Dark Ages Lunar Interferometer) : 10-300 MHz
- LARC (Lunar Array for Radio Cosmology) : up to 150 MHz



Lunar Oribt

- Dark Ages Radio Explorer (DARE) : 40 – 160 MHz

Europe

- Farside Radio Explorer with ESA Lunar Lander

FAST Early Science: Challenge

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Main Technical Difficulties

Error Budget ~2mm

Light Path ~ 150m/300m

beam shape, calibration, and EMC control

Early Science Targets

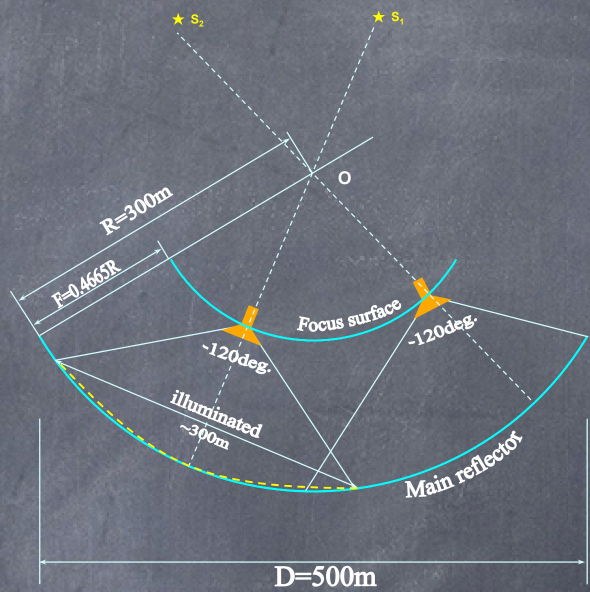
Low Frequency

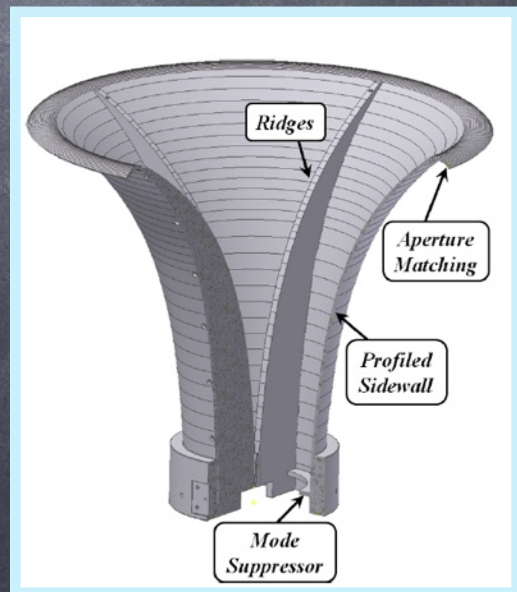
Point Source

Time/Frequency Domain Characteristic

Build an Ultra-wide Band Recevier

Li, Nan, Pan 2012, IAUS291





Key Early Sciences

a) *Pulsar Search in Nearby Galaxies*

M31 is out of Arecibo Coverage

b) *OH Mega-Maser Search*

FAST has 2.3xArecibo Sky +

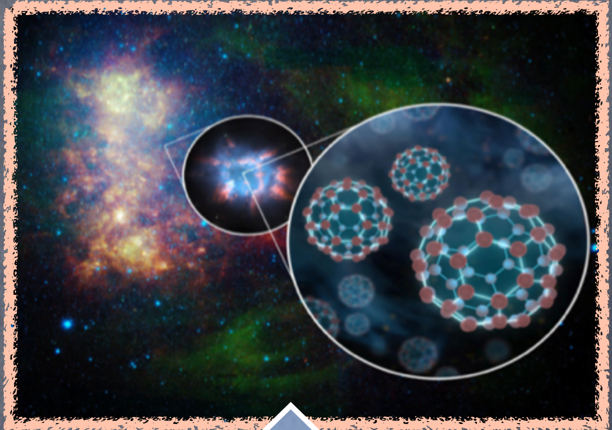
growing IR Galaxy catalogues

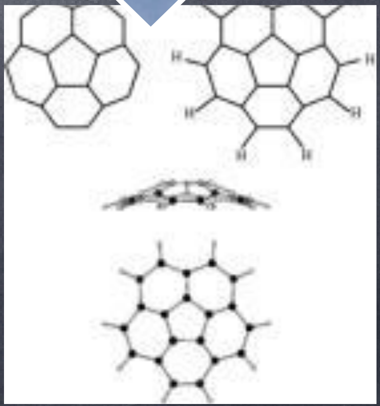
c) *Orion Spectral Line Survey*

Orion is out of Arecibo Sky

Planetary Nebular: C_{60}和C_{70}

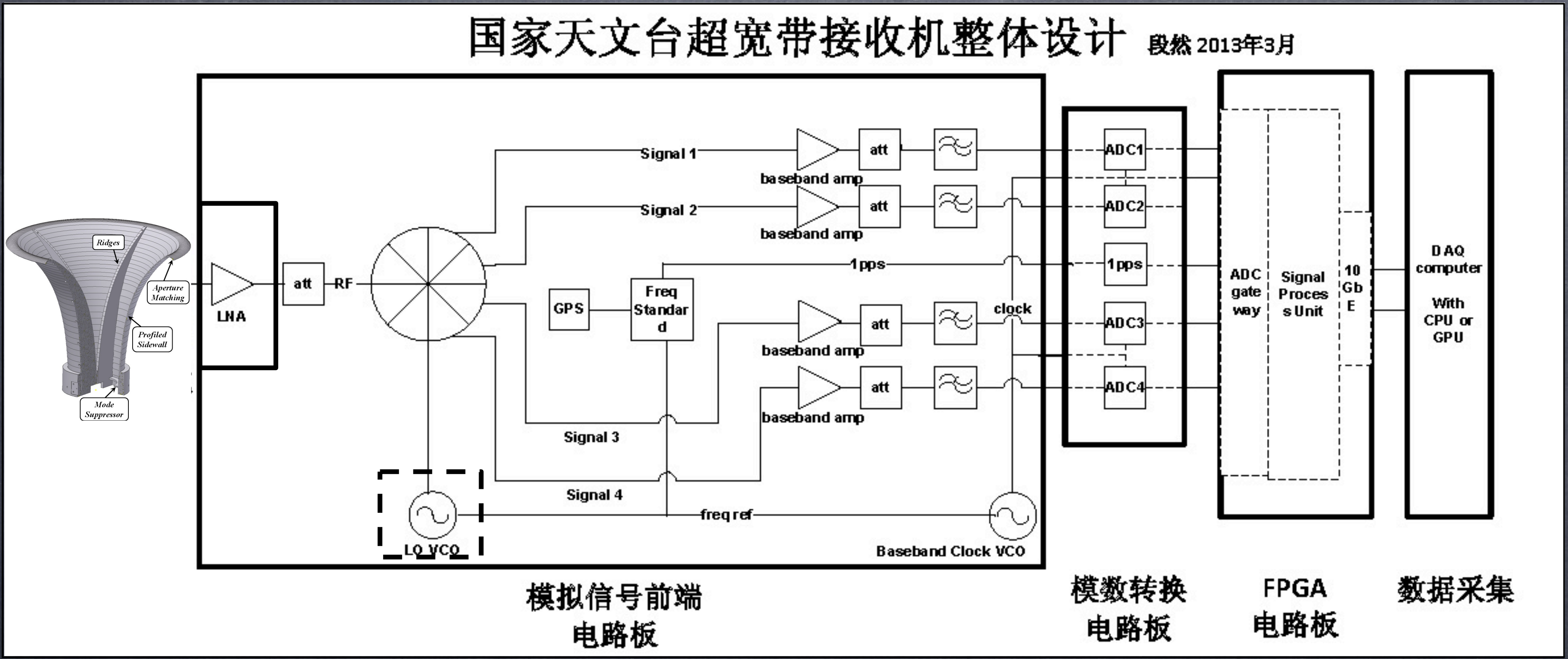
Cami et al. 2010, **Science** 329, 1180





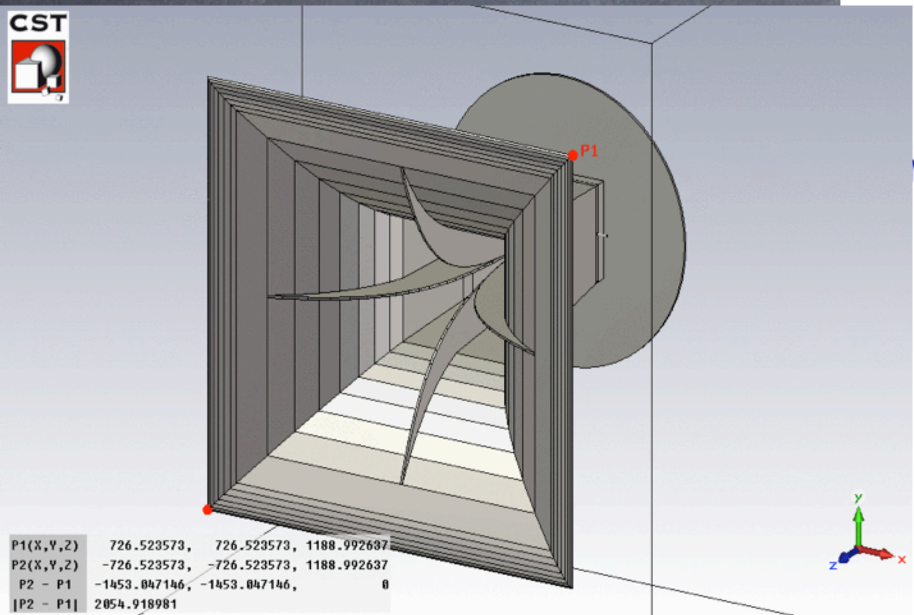
Radio Detection of cosmic carbon structures?

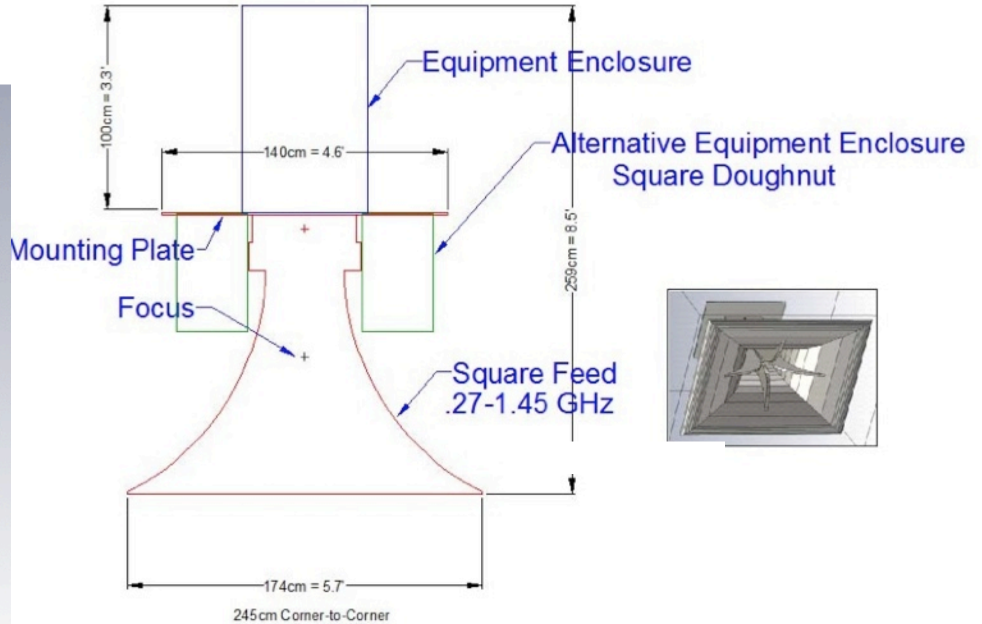
3.Program Goals
COME Schematic Design



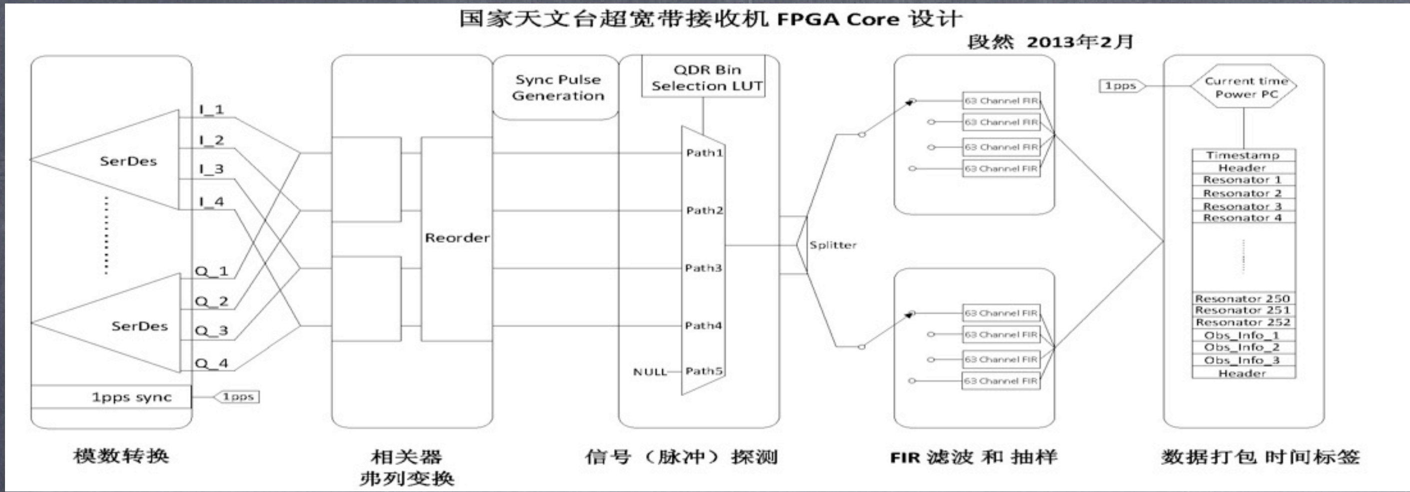
FAST Early Science Feed

超宽带Horn天线设计 0.28–1.68 GHz

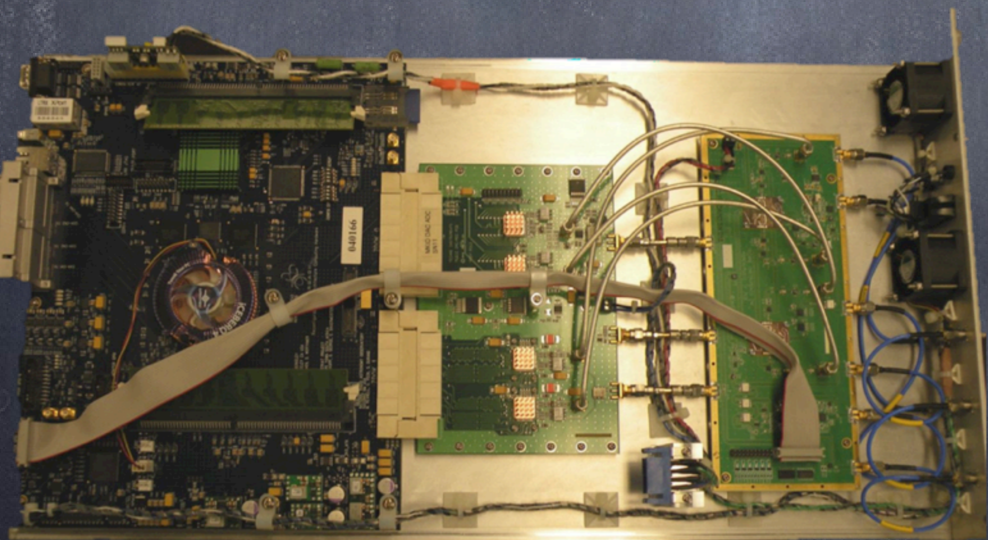




Ahmed Akgiray, Sander Weinreb & William Umbral
"Design and Measurements of Dual-Polarized Wideband Constant-Beamwidth Quadruple-Ridged Flared Horn",
IEEE Antennas and Propagation, 2011



在FPGA上运行的固件和算法上：将采用多级DDC，FFT相结合的办法，实现在3GHz 带宽和12bit ADC精度的情况下，同级别FPGA上最好的频率分辨率；在利用Goertzel等创新算法实现傅立叶变换上进行探索，大幅提高FPGA FFT运算能力



团队成员成功开发过的案例

Main Targeted Specifications

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- 4:1 Frequency Ratio
- Tsys < 30 K
- Flexible Digital Backends 50 - 200MHz
- Best resolution ~ 10 kHz

Development Plan

- Caltech-NAOC joint development of UWSF
- NAOC develops frontend electronics
- NAOC develops ADC boards
- NAOC delivers backend systems

Discover New Molecules

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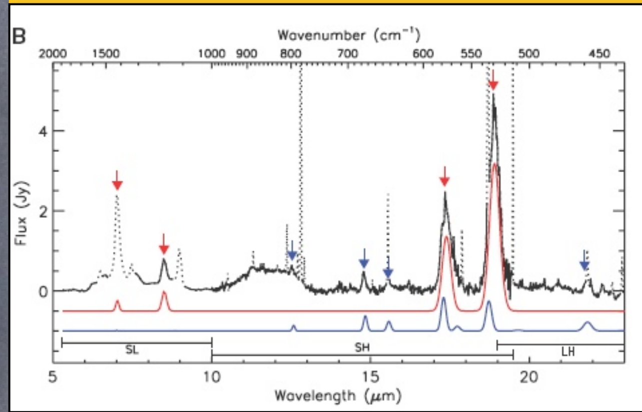
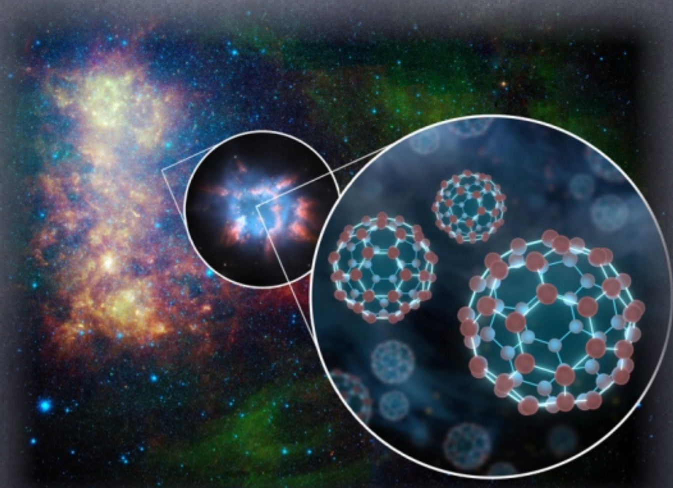
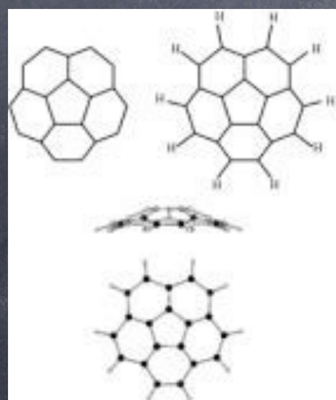
- more than 140 interstellar molecules detected
- FAST: complete line survey in low frequency radio bands
- Search for “Prebiotic” and large organic molecules (Nan, Li, Jin et al. IJMPD 2011)

C_{60}和C_{70}(Buckyballs) in Space





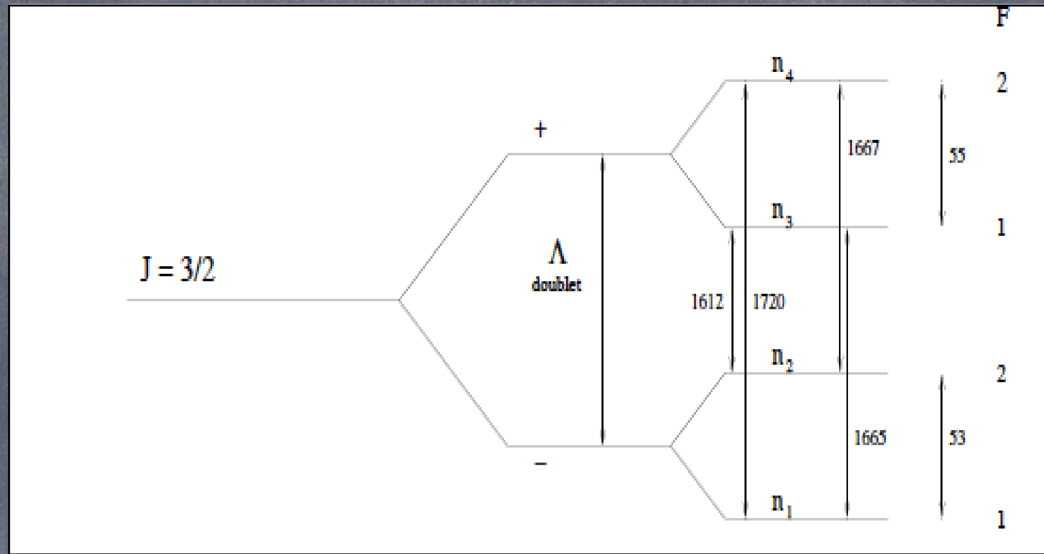


Cami et al. 2010, Science 329, 1180

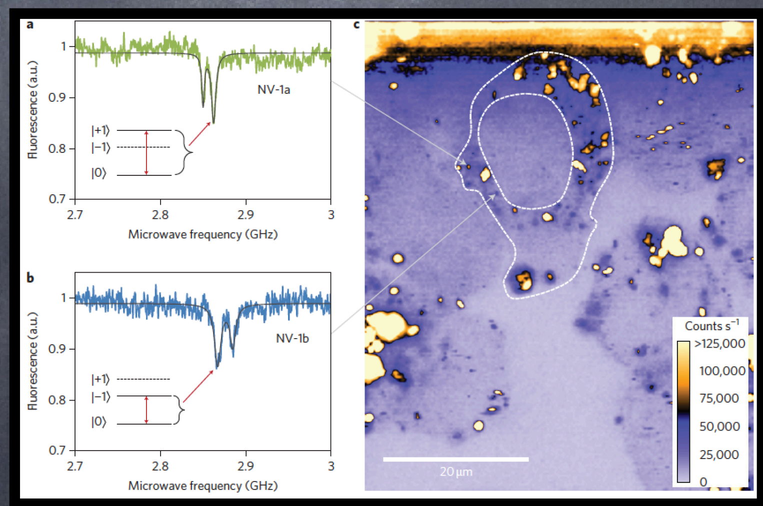
Low Frequency Lines

- Marthi & Chengalur (2010 MNRAS)

  3sigma： 17.3 Jy at 1 km/s resolution



- McGuinness et al. 2011,Nature Nanotechnol., 6, 358



COME: the Future?

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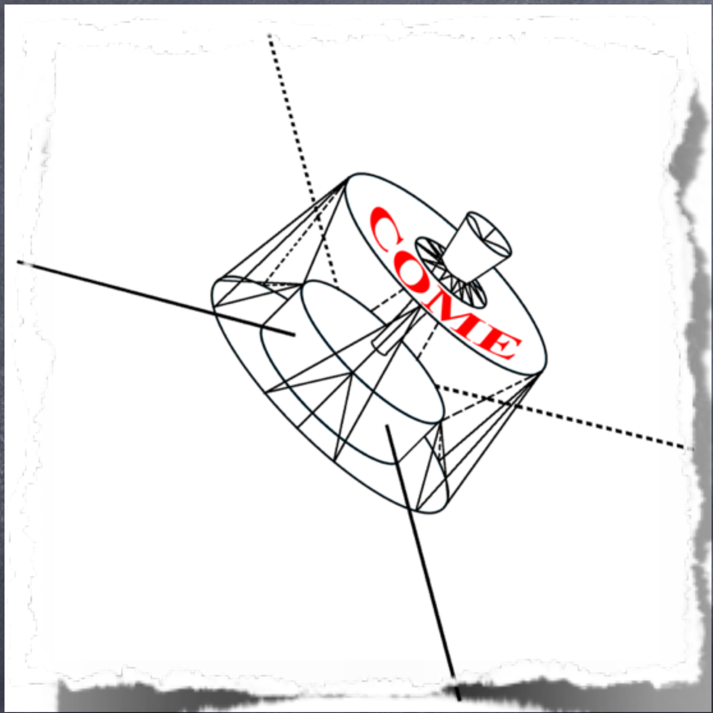
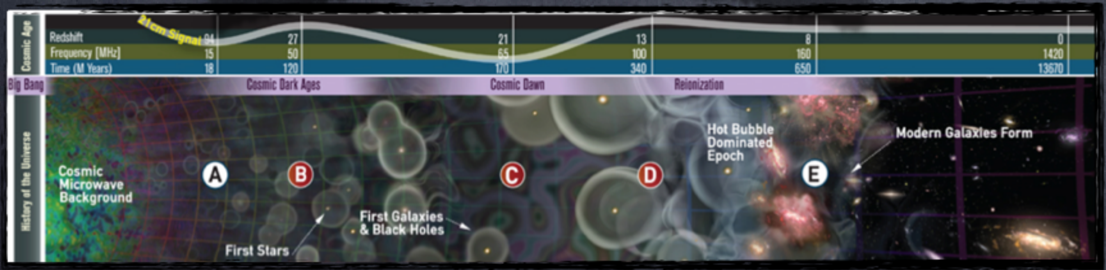
COsmology and Molecule Explorer



Universe

@Beginning
cosmological HI spectrum, recombination ripple

@Now
Reveal faint molecular universe



Summary

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- Gaseous hydrogen is the predominant component of Byronic matter in the universe.
- The global signal of HI 21cm line vs redshift seems to be the most intriguing target of astrophysics in low frequency bands.
- COME aims to utilize the radio quiet space environment to achieve the first detection or credible characterization of the HI global spectrum.
- COME aims to provide low freq. radio inventory of diffuse ISM